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Science and Technology, Autonomous and More Interdependent Every Time

Haydée Santilli

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Abstract In a School of Engineering scientific and technological knowledge live together. Science teachers usually try to understand the role that scientific disciplines have over the engineer training. In this paper are descript three historical case studies that could help teachers and students for better understanding the interdependence between science and technology, and the way in which both are related to society. The cases clearly show that both kind of knowledge, scientific and technological, are autonomous, and that their growths involve complex processes. On this way, learners could have an insight of both, the NOS and the NOT.

1 Introduction

The expansion of mass higher education causes different changes in society. On one hand we find further diffusion specially of technical and scientific knowledge and skills through society; on the other, the necessity of continuing education to generate a better prepared labour force for responding to technological changes (Gibbons et al. 1994).

University teachers wonder how to aim these questions, especially in Schools of Engineering. These institutions often are organized in two cycles: basic and higher. Scientific disciplines and basic technologies are developed along the basic cycle. The higher cycle corresponds to the specific training as engineers. In this kind of organization, scientific and engineering knowledge complement each other to determine the engineer profile that each institution gets. It is clear that engineering knowledge is included into the technological one.

When we teach science we need to know its nature. In early Matthews' words (1994: 83) we find: "*Whenever science is taught, philosophy, to some degree, is also taught. Minimally, the teacher's own epistemology, or conception of science, is conveyed to students and contributes to the image of science that they develop in class*". Paraphrasing

H. Santilli (✉)
Gabinete de Desarrollo de Metodologías de Enseñanza, Facultad de Ingeniería, Universidad de Buenos Aires, Buenos Aires, Argentina
e-mail: hsantil@fi.uba.ar; hsantil5c@gmail.com

Matthews' ideas, we can say: if we want to teach science for engineers, we need to understand, in the same degree, the nature of technology. Then, for getting a good engineering training is important to develop both kind of knowledge, scientific and technological. It is suitable to do that, since students are attending to the basic cycle. It is clearly necessary to understand the differences and similarities of both kinds of knowledge, for a good engineering training.

2 Teaching Issues

It is not easy to teach about either the nature of science (NOS) or the nature of technology (NOT). Matthews (1998, p. 995) affirms: '*To my mind, the nature of science is best approached inductively and tentatively, not didactically*'. He proposes several ways like the discussion of episodes in the history of science, or laboratory exercises, or science-related social issues, and so on. Hence, for understanding the difference between science and technology it is possible analyze historical cases.

Hodson (1992: 130) says: "*…one learns to do science by doing science*." It is not easy to do that at class, but it is possible for students learn about science, analysing adequate case studies. Gorman and Robinson (1998, 174) propose to present case studies to students, where they "*have to make decisions like those an expert would make…*" This is a convenient way to introduce students in both, science-in-making and technology-in-making. Students would understand better the idea of invention and design, which is fundamental for teaching engineering.

We find an interesting example of using history of science and technology (HST) to give a better education to military cadets. It takes place at the United State Air Force Academy. They use case studies throughout the course to illustrate the cultural, social, economic, and psychological dimensions of technology and warfare. They analyses so different cases as the simple technology of Roman *gladius*, the offensive and defensive technologies of medieval knights, the modern tank armor developed, the counter anti-tank missiles, and so on (Astore 2003). On one hand they found that to face HST and technology teaching at the Air Force Academy could be hard for both students and teachers. On their own words: "*engineers and science majors lack the flexibility to enroll in it …Yet they usually see less value in teaching HST to undergraduates and more value in teaching another class of physics, gas dynamics, or their particular sub-specialty*" (p. 192). Despite these difficulties, they found this approach good for students' understanding: "*HST classes at the Air Force Academy address these issues by encouraging cadets to think more critically about the nature of science, technology, and warfare*" (194).

From another point of view, science teaching laboratories may be a good place for developing students' knowledge about science and technology (Tala 2009; Santilli 2008). On this approach, laboratory working must be thought about from Hodson's ideas (1988). There, he proposes that the experimental work goes far beyond of doing activities on a laboratory bench to include activities such as computing, case studies, interviews, discussions and role plays, model designs, posters, scrapbooks, bibliographic researches, and so on. Students could develop there especially empirical knowledge. It is necessary to reorganize the information. This kind of knowledge is essential for the comparison of concepts, which is necessary for students to construct knowledge. It is the basis used to develop cognitive maps where they could anchor new knowledge. It has heuristic and instrumental value for the learning process, and it usually provides a base for an interpretation with which students can assimilate and reinterpret scientific data (Brickhouse

et al. 1993; Paun 1990). Empirical knowledge allows students to acquire scientific skills. Such knowledge helps students solve problems, and thanks to it, they can also perform simple designs. On this way, students are closer both scientific and technological knowledge, even from the early years of their university training. From this point of view, choosing convenient case studies could help students to understand better both, NOS and NOT. In this paper three historical cases that could help them, are presented.

3 First Issues About Scientific and Technological Knowledge

In a School of Engineering scientific and technological knowledge live together. In the basic courses university teachers usually try to understand the role that scientific disciplines have over the engineer training. They could be tempted to suppose that if they do develop the scientific knowledge, that could be enough. This position fits with the "lineal model" for technology, which puts emphasis on scientific knowledge. This model assumes that technology is just applied science (Ciapuscio 1996 y 1994; OECD[1] 1991). An elemental analysis of both, histories of science and technology, shows that both kinds of knowledge are autonomous ones. Vicenti (1990: 4) explains it as follows: "*technology, though it may apply science, is not the same as or entirely applied science*". The research of historians and philosophers of technology clearly points out that technology is not derivative from science; it is an autonomous body of knowledge. In spite of this conception, most of the engineering teachers go on thinking about technology from the lineal model, and this conception causes troubles in understanding for students. The expression "science and technology" is so common that people "*might be tempted to eliminate the spaces between the words and use 'scienceandtechnology' in its place*" (Pitt 2000, 26). Scientific progress, today, is related to technology. This is a bi-directional process that reveals the strong interdependence between science and technology, where technology represents a crucial role in scientific progress (Tala 2009). Despite of the close connection between science and technology and their interdependence, it is important we could differentiate one from the other.

We find a first differentiation between both kinds of knowledge recognizing the technological knowledge as oriented to "knowing how", while the scientific knowledge is concerned about "knowing that". Science explains whereas engineering creates artifacts (Simon 1969).

An indisputable role of science is, among other things, to provide training to staff, which is then used in production. By the other side, since the scientific revolution, science is unthinkable without the use of equipment such as telescopes, spectroscopy, Mössbauer spectrometer, differential scanning calorimeter, and so on. In addition to the specific instruments involved, there are some social issues that must be taken into account for developing modern science, such as, government funding agencies, peer review, career competition, journals, and educational process. "*In the context of the doing science, many of these factors can be viewed as tools to be used and manipulated to achieve specific ends, i.e., as technologies*" (Pitts 2000: 8).

On a commonsense approach for understanding technology, it is possible to characterize technology as "*the organization of knowledge for the achievement of practical purposes*"

[1] Organization for economic co-operation and development.

(Mestheme 1970, in Pitt 2000: 10). This idea of technology involves the design understood as something more than a set of plans, but as a process to produce such plans. We can think about engineering as a problem-solving activity, and design to do it, is a social activity, which "*is intimately bound up with economic, military, social, personal, and environmental needs and constraints*" (Vicenti 1990: 11).

The following table shows a synthesis of the differences between both kinds of knowledge

Scientific knowledge	Technological knowledge
Knowing that	Knowing how
Science explains	Technology is using tools
It comes from the mind of scientists in an attempt to make sense of the natural world	Technology/Engineering creates technics for transforming the natural world
Scientific theories are social constructions for building or modelling the world around us	Technology is the organization of knowledge for achieving a practical purpose
Scientific theories are complex structures that are confirmed or not, in its ability to describe, explain and predict observable phenomena, without being dependent on any observation (Hodson 1986)	Technology involves the idea of design, which is understood as something more than a set of plans, but as a process to produce such plans
It corresponds to the study and understanding of the natural world at a time and a given society	It is associated with the development, production and use of artifacts at a time and a given society

4 Historical Cases

4.1 Relation Between Technical Medieval Revolution and Scientific Revolution

The eleventh century witnessed the development of different procedures that allowed people to take advantage of energy resources coming from water, wind, or animal power; the mill, the crop rotation and the use of the plow, were the best examples. Western people introduced the compass to improve navigation during twelfth century. In that time metallurgical processes were also improved. Both processes, the introduction of the blast furnace, especially for cast iron, and the cupellation that was more often applied for the refinement of lead-silver ores, contributed to improvement of metal outputs. The population's economic growth was responsible for the need for these improvements in the mining and metal production. This growth led to greater demand of iron for horseshoes, guns, bars for construction, or farming tools (Boido 1996; Jacomy 1992; Thuiller 1988).

We can not think about medieval technical revolution in terms of great inventors or of changes coming from a series of breakthroughs. The medival changes came out mainly by small modifications and adaptations, which became at last in a technological shift. Medieval innovations usually did not come from an entirely novel procedure, but from the combination of existing practices. We can appreciate this kind of changes looking towards farming methods. In thirteenth century, more than 70% of the land in some European regions was cultivated with cereal or legumes. This was the result of crop rotation suited to the local resources, and the progressive adjustments that were made during the previous four centuries (Dyer 1997).

Langdon (2008) would agree that medieval technological improvements often followed a path of small changes and adjustments, but there were some notable cases of macro invention that had great influence in the whole society, such as, the introduction of gunpowder weapons and printing. He stressed in particular the innovation of the windmill, in the later twelfth century. It was an anonymous invention from northwest Europe, whose use spread rapidly. Because of its importance and influence at the work and at quality of life, Langdon compares the windmills of the Middle Ages with steam engines of Industrial Revolution.

As seen in the paragraphs above, incremental technical modifications had spread everywhere causing a great impact on the entire society. The production units were moved to areas where there was abundant raw material, power, fuel and transport. Improving maritime transport was generated from the population's enrichment, first for the transfer of wealth. Then, new manufacturing techniques for sailing boats were improved and were shared between the Nordic and the Mediterranean navies. The compass, the new cartographic knowledge, and the improvement of calculations and measurements, allowed beginning open sea navigation (Jacomy 1992). Many artifacts were developed during fourteenth and fifteenth centuries, e.g. mechanical clocks, rudders, instruments for astronomical observation, and so on. The Gutenberg press with its wooden and later metal movable type printing facilitated the dissemination of knowledge because it allowed written materials to be available to more people. This helped the development of craft workshops in the Renaissance (Boido 1996).

The technical developments of the Middle Ages provoked a change in people's attitude. Nature lost its sanctity; it became in something that could be studied by people from the point of view of "causes and effects". Animist beliefs, that all things are alive and animated by divine spirits, became outdated. People changed its attitude in a way explained as "*operational realism*" (Thuiller 1988: 118) or "*the citizen's power just detached from the spiritual power*" (Jacomy 1992: 153).

Just when the Technical Medieval Revolution was in its zenith, the people of European Renaissance highly valued the technical creation. Human beings had a new spirit of inquiry; they had a different attitude towards the natural world. In this context began the Age of Discovery, European people explored the world by ocean searching for trading partners and particular trade goods. New geographical discoveries of fifteenth and sixteenth centuries were realized.

When we analyze all the changes that were made during the medieval technological revolution, we may be tempted to relate them to the Scientific Revolution. However, historians disagree about the causes of the Scientific Revolution. Cohen (1994), in his historiographical study on this subject, shows us that it was a complex social event with many causes. Despite Cohen's position several researchers find that one of the causes of Scientific Revolution was the change of attitude and technical innovations that were done in Middle Age (Bernal 1967; Boido 1996; Easlea 1981; Santilli and Speltini 2003).

4.2 The Invention of the Steam Engine

This event is considered "*the job that changed history*" (Lira 2005) and also a true trigger of the industrial revolution (Arocena 1993). There were several attempts to harness the power of steam from antiquity, but Tomas Savery's attempt, at the end of seventeenth century, was the first which had real success. Savery's steam engine had troubles that made it unsuitable for pumping water out of mines. The first steam engine that had much greater

success was by Thomas Newcomen (Hills 1989, 2000). This engine laid the foundations on which later developments were made, and because of that, Thomas Newcomen was usually considered the inventor of the steam engine, it happened in early eighteenth century. These engines were erected mainly for water pumping, for example in mine drainages.

James Watt, who was considered the most important figure in the history of steam engines, was retained to repair a model Newcomen engine owned by the University of Glasgow (Dickinson 1963). He noticed that this engine had a major loss of energy. Watt recognized that the trouble was due to an undersized boiler that could not provide enough steam to reheat the cylinder after a few strokes. He worked on this problem from 1763 to 1765, this year he built a new machine with a separate condenser, so that the condensation process could take place continuously and the steam cylinder could be pulled to a vacuum while remaining hot and saving fuel at the same time. This stage corresponds to a *technical development*; we can say that Watt's work complements Newcomen's invention, thinking about invention as an absolute novelty with industrial application.

Watt's steam engine was better than Newcomen's, but Watt had to employ great efforts in troubleshooting and developing a full-scale model. He needed economic support to achieve a useful product for the industry: he had two business partners: John Roebuck, from 1768 to 1773, and Matthew Boulton from 1774. Boulton's enthusiasm for new enterprises was sustained; he wanted to build steam engines for everybody. Watt's creative genius, the economic support from Roebuck and Boulton, and the business organization developed by Boulton, were all necessary to go ahead with this project. The technical work of design was developed jointly by Watt and Boulton. This work aimed first to facilitate the assembly, extending component life, improve pricing, and so on. Boulton knew very well the market demands; he was an industrialist of great vision. He saw the possibility to apply the engine to other industries like operating mills and textile factories, etc. In June 1781 he wrote to Watt: "*The people in London, Manchester and Birmingham are steam mill mad. I don't mean to hurry you, but I think in the course of a month or two, we should determine to take out a patent for certain methods of producing rotative motion…There is no other Cornwall to be found, and the most likely line for the consumption of our engines is the application of them to mills which is certainly an extensive field*" (Sproule 1992, in Lira 2005). Watt designed the changes of the steam engine to meet those needs, following Boulton's ideas. The new engine, with a parallel motion mechanism, was created on 1781. Then the steam engine became attractive to the cotton industry. The automating industrial production facilitated the transformation of small factories into large ones. The factories needed to be near water, novel feedstock; they had to move the factories to port cities. The new technology changed social and working organizations. This stage corresponds to a *technological development.* The steam engines changed from curiosities to shapers of both, industry and society. Eighteenth century Soho workshops were anticipated to twentieth century research industrial laboratories (Petroski 1996; Scherer 1965; Santilli and Speltini 2003).

The steam engine case enables us to appreciate the evolution of the concept of invention to innovation, along this stage. We understand innovation as the first attempt to carry out an invention into practice. As we can see from steam engine development, it is a complex process. This new innovation model overcome the linear innovation process which, is characterized either the science-push approach or the demand-pull model. A better model for innovation involves the interaction of science, technology, industry and various economic and social processes (García and Calantone 2002; Manley 2002; Freeman 1995; Nelson 1993; OECD 1991).

It is noteworthy that the science associated with the steam engine was still incipient at Watt's time. The third stage of this process: *science development*, was in its beginning. Watt learned much about steam properties to solve Newcomen's machine problems. He discovered latent heat of vaporization through his experiments. "*One of his University friends was Professor Black, who had discovered latent heat previously and had been lecturing on it without Watt's knowledge. They shared many interesting conversations after Watt told Professor Black of his 'discovery'*" (Lira 2005). He also tabulated the vapor pressure of water at various temperatures before the work of Clapeyron (Heat of vaporization of a liquid), which occurred around 50 years later. From another point of view close to science, they needed to define a unit of power to be included in the royalty system. Watt and Boulton were involved at a business venture where their steam engines substituted horses. Although there were earlier attempts to estimate the effectiveness of steam engines comparing them with horses' work, the estimation made by Watt prevailed (Hills and Pacey 1972; Cardwell 1971). The name given to the power unit,: Horsepower (hp or HP), is still used today.

Science development became crucial with Carnot's work. He analyzed the steam engines for several years; he wanted to find the way to design good steam engines. He was looking for a theory that explained these machines. His work led to the mathematical theory of heat and helped to start the modern theory of thermodynamics, it was published in 1824, on the early nineteenth century. Carnot's ideas were later incorporated into the thermodynamic theory of Clausius and Thomson.

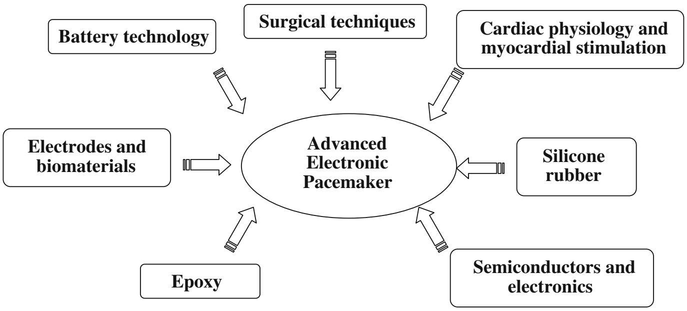
The steam engine is a paradigmatic example that shows how a technical change, steam engine invention, leads to a scientific knowledge, thermodynamic theory. Notably, the influence of science over technology, regarding steam engines, would turn significant almost one century after Watt's invention took place (Petroski 1996; Bernal 1967; Scherer 1965).

4.3 The Design of an Advanced Electronic Pacemaker

The above cases are distant in time, and it could be interesting compare them with more recent history. One feature of current innovation is its close and growing ties with scientific research. It is unthinkable that the development of a new technology would occur without resorting to some skills from science. But, advances in science are also increasingly dependent on technology. At the present time, innovation fully integrates both approaches: scientific and technological. As was said above, today concept of innovation involves a two-ways process between science, technology and industrial development.

The design of an advanced electronic pacemaker is an interesting way for illustrating the above interdependencies. This is a current case that exemplifies the multiple interactions involved between science, technology and society. Its management has included several lines of research and development, such as: semiconductors and electronics, battery technology, surgical techniques, cardiac physiology and myocardial stimulation, electrodes and biomaterials, epoxy, and silicone rubber (Batelle Columbus Laboratories[2]). The following diagram shows those lines.

[2] Batelle Columbus Laboratories: 1973, Interactions of science and technology in the innovative process: some case studies, for the National Science Foundation NSF.



First, it is desirable to describe how a pacemaker works. A healthy heart maintains an adequate number of synchronous beatings. It has its own system of generating and conducting of electrical impulses. When the heart can not do it properly, it is necessary to use a pacemaker. This is a small-sized device, which contains a battery and the electronic circuit that runs the pacemaker, along with one or two long thin electrical wires that travel from the pacemaker device to the heart. Pacemakers apply electrical stimulus on the heart to increase heart rate. The knowledge associated with the operation of pacemakers comes from physics, especially electricity and portable sources of electricity, and medicine. To illustrate the interdependence between the different kinds of knowledge, we are going to develop several episodes from the above research lines.

Related to portable power sources and the effects of electricity on living organisms, we must go back to the eighteenth century. In Italy there were two major competing schools in the development of electricity knowledge, one at Pavia led by Volta, and the other at Bologna led by Galvani. Galvani was primarily interested in physiology. He made significant progress in the knowledge of animal electricity. He studied the effects of electrical discharges occurring on the animal nerves. Galvani experimented in several areas of science such as electricity, anatomy, medicine, and so on (Focaccia and Simili 2007; Kipnis 2003; Binnie 2001; Bernal 1967). The analysis of the "animal electricity" has been of great value to medicine, and to physiology, especially for studying human heart. Volta repeated Galvani's experiments; he confirmed his results, but came to a different, and startling, conclusion. Volta had developed a more logical way of working than Galvani. He tried to produce electricity without using animals. He used several discs of different metals, zinc and brass as Galvani had, placed alternately and separated by other discs in cardboard soaked in a solution of salt water. Volta's experiment led to postulate the existence of two types of drivers: first class or dried, metals, and second-class or wet, saltwater.

Volta's invention had the possibility of producing a continuous electric current; this allowed the development of new branches of science, as electrochemistry and electromagnetism (Binnie 2001). However, Volta did not appreciate that the voltage was due to chemical reactions, as Michael Faraday showed in 1834. Volta found that if two different metals are immersed in saltwater, a constant flew of electricity was produced. That is why he is regarded as the inventor of the voltaic battery, in 1799 at Pavia University. Both, Galvani's and Volta's works had led to the development of batteries; which was a fundamental step for the operation of the pacemaker. However, it took much time considering that both scientists were geared toward the same achievement.

Despite this early beginning related to portable power sources, only at the mid-nineteenth century actions on this line can relate to the management of the pacemaker. The invention of the "dry cell battery" (zinc–manganese dioxide) in 1866 by George

Leclanché, was considered a decisive step to this end. This system still dominates the world market for primary batteries. There were several oriented researches (OR) that culminated with the patents for both, carbon–zinc dry cell, and alkaline Nickel–Cadmium rechargeable cell,[3] during the 1880s and the 1890s. Some achievements are detailed on the following table[4]

Decade	Protagonist	Development
1860	Leclanché (France)	Dry cell invention (zinc–manganese dioxide)
1870	Society	The telephone industry created the next major leap forward in the demand for batteries
1880	Carl Gassner (USA)	Patent for the carbon–zinc dry cell, which made batteries the convenient power source they are today
1890	Waldemar Jungner (Sweden)	First patent on nickel–cadmium rechargeable cell using alkaline chemistry
1900	Thomas Alva Edison (USA)	Patents a rechargeable alkaline cell, the Nickel Iron (NiFe) battery
1920	Samuel Ruben (scientist)	
Philip Rogers Mallory (manufacturer; USA)	The union of one's inventive genius with the other's manufacturing capacity, was the bedrock of Duracell international	
1930	Sabine Schlecht and Hartmut Ackermann (Germany)	Invention of the porous sintered pole plate, bringing about major improvements to Ni-cad battery design.
1940	Samuel Ruben and	
Philip Rogers Mallory (USA)	The war years stimulated the development of new cell chemistries with water-activated batteries, silver oxide and mercuric oxide cells after over 40 years with few major advances.	
1940	Neumann (France)	Successful seal for the nickel–cadmium battery
1950	Samuel Ruben (USA)	Improvement the alkaline manganese battery
1950	Mallory Battery Company	Introduction of the alkaline manganese cells in a new size, the AAA.
1950	Lew Urry (Canada)	Patented the first modern primary alkaline battery, improving Ruben cell

[3] See note 2.

[4] Data from the following websites (consulted on March 2009): http://www.duracell.com/company/history.asp?id=50&, http://www.ideafinder.com/history/inventions/battery.htm, http://www.mpoweruk.com/history.htm.

Decade	Protagonist	Development
1960	Waldemar Jungner (Sweden)	Development of the first nickel–cadmium rechargeable battery system
1960	Duracell/Eveready	The high demand of batteries provoked a great deal development in both companies
1960	Wilson Greatbatch (USA)	Development of long life Lithium Iodine primary battery which a first totally implantable heart pacemaker made possible

Edison's research group was responsible for the first steps on another research line: semiconductors and electronics. Edison set up his famous laboratory at Menlo Park; he built this laboratory with his earnings from the telegraph business. This was a large research group, which included engineers and other workers. Menlo Park laboratory became the first institution set up with the specific purpose of producing constant technological innovation and improvement. There, they were produced many inventions that led to the registration of a large quantity of patents. This group made a significant discovery in basic research (BR), the Edison effect: electrons flowed from incandescent filaments, in the 1880s. This episode could be considered the first step in modern electronic science (Waits 2003; Bernal 1967; Clement 1920).

Pacemaker management also involved some experimental developments (ED), for example, which led to a patent for a water intracardiac bipolar electrode,[5] in the 1930s. Other decisive ED was the construction of an artificial pacemaker for intracardiac therapy, also in the 1930s (Aston 1991). Dr. Albert Hyman patented the first artificial pacemaker,[6] on 1933. It was a small device, which emitted electrical stimuli in order to restart the "stopped heart". Albert Hyman employed the artificial pacemaker on small laboratory animals (rabbits, guinea pigs, and "one large dog"); the invention had revived 14 out of 43 animals (Jenkins 2008).

There were many significant events associated to this technological innovation. A decisive one was the ED culminated in the patent of the transistor. Three American physicists at the Bell Telephone Laboratories invented it, at late 1947.[7] Transistors are semiconductors; with them started a new scientific branch: microelectronics, whose further development would lead to integrated circuits and microprocessors. Integrated circuits, which replaced the original transistors, allowed both, the manufacture of smaller pacemakers, and their programming. These new pacemakers enabled communication in two ways: from the specialist to the pacemaker, and back to the specialist, by using electromagnetic waves (telemetry) and not by magnetic fields as hitherto.

Another decisive event, on cardiac physiology and myocardial stimulation line,[8] were the OR that culminated with the possibility of repairing the atrioventricular block due to

[5] See note 2.

[6] See note 2.

[7] http://www.juliantrubin.com/bigten/transistorexperiments.html. Consulted: April 2009.

[8] See note 2.

surgical trauma, and also, the treatment of this blockade using electrodes directly to the myocardium, both researches in the 1950s.

The birth of the cardiac stimulation is associated to Hyman's experiments. He was the first to stimulate a heart with an external pulse generator; inserting the wires into the chest to the heart did it, and a hand crank loaded the device. However, Dr. Senning was the first that started cardiac stimulation, as understood today, using a pacemaker with the stimulus generator implanted in the body. He placed the first implantable pacemaker in a 43-year-old man with Stokes-Adams syndrome in late 1958. He used a pacemaker designed by the engineer Rune Elmquist. The original device had to be replaced almost 30 times, but it was not a failure because the patient was enjoying a normal life at age 83 (Cooley 2000).

The power source was a critical problem for pacemakers in the late 1960s. These pacemakers get their power from mercury–zinc cells which, lasted less than 2 years on average. To solve this problem required great ingenuity involving different concepts, such as, rechargeable pacemaker batteries, a biogalvanic cell, bioenergy sources, nuclear generators, and batteries based on lithium chemistry. Nuclear pacemakers worked well, but public uneasiness about nuclear safety and excessive paperwork and environmental concerns might have doomed this kind of power source. Finally, manufacturers had found the solution using a lithium battery (Jeffrey and Parsonnet 1998). The solution of this problem involved issues beyond the development of science. It was necessary that several sources of innovation were developed for solving it. Pacemaker manufacturers also needed to take into account the reaction of public opinion against the use of nuclear sources.

As we saw previously, some significant events were neither scientific nor technological. An interesting example was the case of social demand for using dry batteries[9] in the radios during the 1920s. From another point of view, for Hyman it was not enough to develop cardiac stimulation, he also had to go far away to provide an acceptable rationale for electrical cardiac stimulation. He needed the acceptance of physicians and society,[10] in the 1930s (Furman 2001). Other example was the development of batteries and insulating materials during the II World War,[11] in the 1940s.

5 Reflections About Science, Technology and Science Teaching

These cases were selected for recognizing the importance of technology, for helping especially science teachers working at Schools of Engineering. The cases show the "day by day" development of technological advances, its connection with science, industry and society. When science teachers or students analyze these historical cases, they can appreciate the complexity of the process that culminates in a new technology. This kind of historical analysis takes into account several factors associated with the chronological facts, such as, socio-political situation, economical or management problems, epistemological issues, and so on. In this way, teachers and students could understand scientific or technological processes better than doing the same with the facts of the current science or technology. This assumption is based on Price's ideas (1963); he claims that analyzing Galileo's or Planck's works, from a historical perspective, may be more effective than doing so with the work of present-day scientists, for understanding the operation of

[9] See note 2.

[10] See note 2.

[11] See note 2.

science. We assume it is possible to extend this analysis to technology, and also to the training of human resources working in these fields. From this perspective we find that Vicenti (1990) explains what the engineers know, and how to do it, through historical research of case studies at engineering schools, in the United States of America. This idea of learning or better understanding about NOS is supported also by Höttecke (2000); he focuses on replicating historical experiments. On this way of rebuilding an experiment and redoing the experimental performance, teachers and students become closer to scientific work.

From this point of view, the analysis of historical cases could help teachers and students to understand the complex interactions between science, technology, industry, and economical and social processes. The following are some examples that show a way for using historical cases in science teaching. There are described possible scenarios and classroom activities.

5.1 Extracurricular Courses for Teacher Training (for Science and Engineering Teachers)

Teachers will receive writings of the historical cases and a guide for group discussion. They will form three discussion groups; each one will choose one historical case. After each small group discussion, groups will share their ideas about NOS and NOT. It could be appropriate show their findings in writing, for each group.

5.2 Curricular Presentation for Engineering Students

5.2.1 Technical Medieval Revolution (Introductory Class in First Physics Course)

First Physics students learn classical mechanics; it would be desirable that they understand the relationship between science, technology and society. Students will form small discussion groups, in the introductory class. Each group will receive a write-up of the historical case and a guide for group discussion. After each small group discussion, they will write on a paper their ideas about the technical changes and their influences on society, the change in human attitudes, and the student's ideas about science. The groups then will reassemble in a plenary session. This process would enable students to share their ideas even though the classes were numerous.

5.2.2 The Invention of the Steam Engine (Thermodynamics Course)

Contextual learning is a proven concept (Crawley et al. 2008). This approach to learning and teaching allows students to make sense of new knowledge related to their context. Usually the physics teaching is contextualized from science or from everyday life. This historical case allows introducing the teaching of thermodynamics from a technological context.

5.2.3 The Design of an Advanced Electronic Pacemaker (As Training Before the Development of Their Professional Final Work)

The professional final work should show how the students integrated their knowledge of science and technology. Today engineers are expected to solve problems and make designs

taking into account among other factors, the economy, environment and security. Reflecting on this historical case, students can take a holistic view about the ways of working of scientists and engineers, showing also the importance that society has in all these processes. The discussion in small groups facilitates the expression of student ideas about science and technology. Such reflections could improve the quality of professional work carried out by the students beyond the technical quality of it.

The historical cases described show clearly that science and technology are both autonomous and interdependent. It is possible to see also the role of society in a bi-directional way. On one hand, both, science and technology change society; on the other, social necessities and demands that generate changes in science or technology. This historical view would allow us to better understand the processes involved in the development of both knowledge, scientific and technological. This kind of analysis facilitates to learners an insight into both the NOS and the NOT.

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